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INVESTIGATION OF SOIL CONSERVATION SERVICE URBAN HYDROLOGY TECH--ETC(U)

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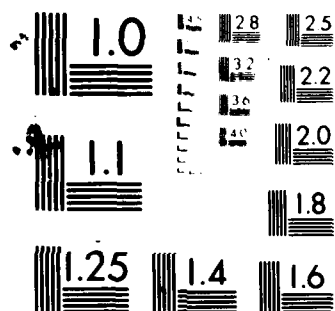
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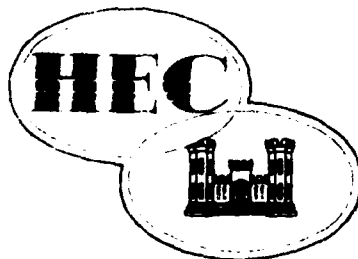
by

Duke G. Altman

William H. Espey, Jr.

Arlen D. Feldman

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Technical Paper No. 77	2. GOVT ACCESSION NO. HD-41097-1	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Investigation of Soil Conservation Service Urban Hydrology Techniques		5. TYPE OF REPORT & PERIOD COVERED
7. AUTHOR(s) Duke G. Altman, William H. Espey, Jr. and Arlen D. Feldman		6. PERFORMING ORG. REPORT NUMBER
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army Corps of Engineers The Hydrologic Engineering Center 609 Second Street, Davis, CA 95616		8. CONTRACT OR GRANT NUMBER(s)
11. CONTROLLING OFFICE NAME AND ADDRESS		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		12. REPORT DATE May 1980
		13. NUMBER OF PAGES 14
		15. SECURITY CLASS. (of this report) Unclassified
16. DISTRIBUTION STATEMENT (of this Report) Distribution of this publication is unlimited.		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		Accession For NTIS GRA&I <input checked="" type="checkbox"/> DTIC TAB <input type="checkbox"/> Unannounced <input type="checkbox"/> Justification
18. SUPPLEMENTARY NOTES Presented at the American Geophysical Union U.S. - Canada Hydrology Symposium, Toronto, May 1980		By Distribution/ Availability Codes Dist Avail and/or Special A
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Urban hydrology, Curve numbers, Flood Frequency, Design storm, Calibration.		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The application of the Soil Conservation Service (SCS) urban hydrology techniques is made to four watersheds. The parameters of the methods are obtained from standard SCS guidance and from calibration of watershed model HEC-1 using the SCS method. A modified method of determining these parameters is also recommended to SCS runoff parameters are then used with design storms to illustrate the differences in frequency curves which may result.		

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

## INVESTIGATION OF SOIL CONSERVATION SERVICE URBAN HYDROLOGY TECHNIQUES<sup>a\*</sup>

By Duke G. Altman<sup>1</sup>, William H. Espey, Jr..<sup>2</sup> and Arlen D. Feldman<sup>3</sup>

### INTRODUCTION

Today's engineer/hydrologist is often required to estimate flood discharges for various recurrence intervals in urban areas having little or no local rainfall and/or runoff data. Since rainfall frequency information is available for most of the country (e.g., National Weather Service-Technical Paper 40, 1961), methods that transform rainfall into runoff are often used to make these estimates. Some widely used methods can be grouped as: 1) rational method equations; 2) synthetic unit hydrograph methods; 3) regional flood frequency equations; and 4) kinematic wave methods. Quite often the synthetic unit hydrograph method is selected due to limitations of the other methods.

Two traditional synthetic unit hydrograph methods, the Snyder Method (Snyder, 1938) and the Clark Method (Clark, 1945), rely heavily on coefficients that are related to watershed physiography and/or runoff characteristics. These coefficients must be adequately determined to sufficiently define the time-varying flow ordinates of the unit hydrograph. To accurately define the effect of urbanization on these two coefficients, and ultimately the unit hydrograph shape, an analysis of regional or hydrologically similar urban watersheds is required; however, there is still a large number of areas where these studies have not been done due to a lack of need and/or data. Empirical unit hydrograph equations as reported in Espey *et al.*, (1965), Espey *et al.*, (1968), Hamm *et al.*, (1973) and Espey, Altman and Graves (1977) offer other means of obtaining synthetic unit hydrographs based on the physiographic and urban characteristics of a watershed. These equations were developed from data on watersheds located throughout the United States.

The Soil Conservation Service (SCS) methods in urban hydrology are outlined in SCS-TR-55 (SCS, 1975) and have been developed in a generalized fashion to allow for relatively straight-forward determinations of storm runoff magnitudes, time-sequence and volume that appear applicable in many urban studies. For the more complex hydrologic investigations in urban areas, the National Engineering Handbook-Section 4 (SCS, 1971) and SCS-TR-20 (SCS, 1973) model can be utilized with SCS-TR-55 procedures to more precisely describe the runoff process.

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<sup>a</sup> Original work funded by the U.S. Army Corps of Engineers, Hydrologic Engineering Center, Davis, Calif. and included in the report "An Evaluation of the Effects of Urbanization on Flood Discharges" by Espey, Huston & Assoc., Inc. (1979).

<sup>1</sup> Sr. Staff Engr., Espey, Huston & Assoc., Inc. Austin, Tex.

<sup>2</sup> Pres., Espey, Huston & Assoc., Inc. Austin, Tex.

<sup>3</sup> Chief, Research Branch, HEC, U.S. Army Corps of Engineers, Davis, Calif.

\* Paper presented at the American Geophysical Union U.S. - Canada Hydrology Symposium, Toronto, May 1980.

The SCS curve number method of determining rainfall loss rates is easy to use because it is based on soil and land use characteristics that are generally determinable from existing information. However, rainfall intensity is not considered in the method and only daily rainfall-runoff records from small agricultural watersheds were used in its development. The effect of urbanization on rainfall loss rates is dependent on the selection of appropriate curve numbers. Some problems may also be encountered in accurately determining an urban areas' curve number due to the compaction of soil by heavy equipment, inability to estimate variable vegetation conditions, introduction of fill material and mixing of surface and subsurface soils.

SCS relationships for hydrograph lag time in urban areas are based on limited data and analysis so additional study and evaluation is definitely needed. Use of a dimensionless unit hydrograph derived from numerous unit hydrographs for rural watersheds and then modified to reflect urban runoff relationships has a degree of uncertainty associated with it. However, familiarity with using the SCS method and the hydrologic processes involved will overcome much of this uncertainty.

In order for the professional community to gain confidence in the ability of SCS methods in predicting the effects of urbanization or flood discharges, these methods must be evaluated with data from a number of watersheds having a range of physiographic, urban and climatic conditions. The purpose of this study is to provide data and information to which additional evaluations can be added and allow for a better appreciation and understanding of the advantages and limitations of the SCS urban hydrologic techniques.

#### WATERSHEDS STUDIED

An urban and a matching undeveloped watershed were selected in each of two "regions" as study areas. The selected watersheds in each region have similar climatic and physiographic features. In this manner the hydrologic effects of urbanization are isolated to allow testing of the SCS procedures in evaluating such effects. The Waller and Wilbarger Creek watersheds were respectively chosen as the urban and undeveloped areas in the Austin, Texas region while the Turtle Creek and Spanky Branch watersheds respectively represent the urban and undeveloped areas in the Dallas, Texas region. Table 1 summarizes the physiographic and urban conditions of the four watersheds selected for analysis.

Since the Waller Creek watershed was undergoing urbanization during the period of record of rainfall and runoff gaging, it is studied for three distinctly different periods (degrees) of urbanization as shown in Table 1. The Turtle Creek watershed was fully urbanized prior to the regular analysis of storm event data by the U. S. Geological Survey (USGS) allowing only one urban condition to be studied.

#### CALCULATED VERSUS OPTIMIZED CURVE NUMBERS AND LAG TIMES

The first means of evaluating the SCS urban hydrologic techniques is accomplished by determining and comparing "calculated" versus "optimized" values of SCS runoff curve numbers (CNs) and hydrograph lag times (TLs) for the four watersheds.

TABLE 1  
WATERSHED PHYSIOGRAPHIC FEATURES, LAG TIMES AND CURVE NUMBERS

Watershed (USGS Gage No)	Date(s)	A (sq mi)	CS (ft/ft)	WS (ft/ft)	L (ft)	Lca (ft)	I (%)	MIL (%)	TL (C) (hrs)	TL (A) (hrs)	TL (O) (hrs)	CN (C) (--)	CN (O) (--)
<u>Austin, Texas</u>													
<u>Region:</u>													
Waller Creek at	1957-59	4.13 <sup>(1)</sup>	0.009 <sup>(1)</sup>	0.027 <sup>(2)</sup>	27,600 <sup>(3)</sup>	10,500 <sup>(1)</sup>	24.5 <sup>(1)</sup>	37 <sup>(2)</sup>	1.74	--	--	84	92
23rd Street	1962-65						31.3 <sup>(1)</sup>	37 <sup>(2)</sup>	1.62	--	0.60	84	79
(08157500)	1964-75						40 <sup>(2)</sup>	40 <sup>(2)</sup>	1.50	0.90	0.36	84	81
Wilbarger Creek	1964-75	4.61 <sup>(1)</sup>	0.0074 <sup>(1)</sup>	0.026 <sup>(2)</sup>	20,000 <sup>(2)</sup>	10,500 <sup>(2)</sup>	--	--	1.98	1.74	1.50	83	85
(08159150)													
<u>Dallas, Texas</u>													
<u>Region:</u>													
Turtle Creek	1967-76	7.98 <sup>(4)</sup>	0.0053 <sup>(4)</sup>	0.019 <sup>(2)</sup>	31,200 <sup>(4)</sup>	14,700 <sup>(2)</sup>	47 <sup>(4)</sup>	15 <sup>(5)</sup>	2.10	1.20	0.78	86	93
(08056500)													
Spanky Branch	1973-75	6.77 <sup>(4)</sup>	0.0069 <sup>(4)</sup>	0.026 <sup>(2)</sup>	25,800 <sup>(4)</sup>	12,500 <sup>(2)</sup>	--	--	2.46	2.34	1.56	84	96
(08057120)													

Abbreviations:

A = drainage area; CS = channel slope; WS = average watershed slope; L = main channel length; Lca = main channel length from mouth to opposite centroid of watershed; I = impervious cover; MIL = modified hydraulic length of main channel; TL (C) = watershed lag time calculated from Eq. 3-2 of SCS (1975); TL (A) = watershed lag time determined from an "alternate" method (see text); TL (O) = watershed lag time "optimized" from observed storm events utilizing HEC-1 (USCE, 1979); CN (C) = watershed curve number "calculated" from land use information, soil data, Table 2-2 of SCS (1975), and Table 9.1 of the SCS National Engineering Handbook; CN (O) = watershed curve number "optimized" from observed storm events utilizing HEC-1.

References:

- (1) USGS records (Stade, 1979)
- (2) Computed utilizing topographic maps, land use maps, aerial photographs, field surveys, etc.
- (3) Espey (1965)
- (4) Dempster (1974)
- (5) Black (1979) pers. comm.

The general method used to calculate CNs for each of the four watersheds is outlined as follows:

- 1) Determine the areal portions covered by the different SCS hydrologic soil groups and land use/cover conditions utilizing detailed and/or general SCS soil maps, aerial photographs, land use maps and discussions with local SCS and city officials (see Tables 2 and 3). Calculate a CN representative of the entire watershed utilizing the procedures outlined in Sections 7, 8 and 9 of SCS (1971) and Table 2-2 of SCS (1975) (see Table 1).

Equation 3-2 of SCS (1975) was selected as one of two methods of calculating watershed lag times as the data was available to allow use of a consistent method in each watershed. This equation is provided below:

$$TL(C) = \frac{l^{0.8}(S+1)^{0.7}}{1,900 Y^{0.5}}$$

where  $TL(C)$  = calculated watershed lag time (hours)

$l$  = hydraulic length of watershed (feet)

$S = \frac{1,000}{CN'} - 10$  ( $CN'$  is a retardance factor and is equivalent to the runoff curve number)

$Y$  = average watershed slope (percent)

Values of  $TL(C)$  in Table 1 represent the "calculated" method utilizing this equation. Input data used in the equation are also presented in Table 1. The general method used to calculate respective watershed  $TL$ s is outlined below.

- 1) Evaluate Equation 3-2 of SCS (1975) utilizing the physiographic/urban conditions listed for each watershed in Table 1.
- 2) Adjusting the lag time for each urban watershed obtained in 1 (above) utilizing Figs. 3-4 and 3-5 of SCS (1975). Values for  $CN(C)$ , percent of main channel modified (MHL), and percent of watershed impervious cover ( $I$ ) used to evaluate the necessary lag time adjustment with Figs. 3-4 and 3-5 are found in Table 1.

The second method of calculating lag times was developed after a review of the results obtained from Equation 3-2 (SCS, 1975) appeared low for the urban watersheds when compared to results of other methods. Since the determination of calculated lag times directly affects other evaluations in the overall investigation of SCS techniques (such as subsequently provided in the peak discharge frequency curve analysis), an alternative method was also used. This alternative method is based on lag time relationships developed by Carter (1961), Eagleson (1962), Van Sickle (1962), Espey (1965), and Espey, Altman and Graves (1977). Each watershed was evaluated by techniques outlined in the listed references in addition to overland and channel travel time estimates and a representative lag time obtained from the results. The lag times developed from this alternative method are denoted as  $TL(A)$  values in Table 1.



TABLE 2  
WATERSHED HYDROLOGIC SOIL GROUP AREAL COVERAGE

Watershed	SCS Hydrologic Soil Groups (% of Watershed)				
	A	B	C	D	Total
<u>Austin, Texas Region</u>					
Waller Creek	—	1	87	12	100
Wilbarger Creek	—	—	51	49	100
<u>Dallas, Texas Region</u>					
Turtle Creek	—	8	51	41	100
Spanky Branch	—	—	23	77	100

TABLE 3  
WATERSHED LAND USE/COVER AREAL COVERAGE

Watershed	Land Use/Cover Classifications (% of Watershed)										
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
<u>Austin, Texas Region</u>											
<u>Waller Creek</u>											
1958	11.1	7.3	55.0	5.3	12.6	8.7					
1964	12.3	7.3	56.7	5.3	15.0	3.4					
1973	13.6	7.5	57.3	5.6	12.6	3.4					
Wilbarger Creek						50.3	25.6	7.3	15.5	1.3	
<u>Dallas, Texas Region</u>											
Turtle Creek	15.9	6.6	58.9	8.7	8.9	1.0					
Spanky Branch						33.1	55.1		10.6		1.2

NOTE: (1) = Commercial; (2) = Industrial; (3) = Single-family residential; (4) = Multi-family residential; (5) = Parks; (6) = Pasture/range/grassland; (7) = Row crops (straight row); (8) = Row crops (contoured); (9) = Row crops (contoured and terraced); (10) = Wooded; (11) = Roads

The HEC-1 computer program was used to optimize CN and TL values representative of each watershed and, in the case of the Waller Creek watershed, three different urban time periods. Storm rainfall and runoff data from USGS for several events were used in the optimization process for each watershed. The storms selected had relatively large peak discharges (in a single peak, if possible) and evenly distributed temporal and spatial rainfall throughout the watershed of a relatively constant intensity. Table 4 lists the dates of storms utilized along with other storm-specific information.

The methods used to obtain the optimized CN values representative of each watershed are given below.

- 1) The 5-day antecedent moisture conditions (AMC) previous to each storm was obtained from USGS daily rainfall files and is provided in Table 4.
- 2) An AMC-II CN was determined from Table 10.1 of SCS (1971) for each storm for which an optimization analysis was performed. These determinations are provided in Table 4.
- 3) The results from 2 (above) were then used to select a representative Condition II CN for each watershed and, in the case of Waller Creek, each time period. These Condition II CN values are denoted as CN(O)s in Table 1.

Due to difficulties such as finding storm events with spatial and temporal uniform rainfall over the watershed and the unsynchronized timing of observed hydrographs with their related hyetographs that can occur, it was determined that the results of the individual storm HEC-1 optimizations of lag times require a more selective review than the approach used in obtaining the optimized CN values. This process is generally described below and the results are presented in Tables 1 and 4.

- 1) The HEC-1 optimizations were reviewed closely to identify those storms having acceptable computed versus observed (recorded) runoff hydrographs. Hydrograph timing and peak discharge comparisons between the computed and observed hydrographs were considered to be the most important factors in measuring the suitability of each optimization.
- 2) An additional review was given the collective results of the several storm optimizations performed for a single watershed or a watershed urbanization time period in an effort to select the best representative lag time.

#### WATERSHED PEAK DISCHARGE FREQUENCY CURVES

To test the SCS hydrological techniques in determining peak discharge frequency curves, annual series and synthetic frequency curves were developed for a comparative analysis. Annual series frequency curves for each of the four

TABLE 4  
WATERSHED STORM DATES, ANTECEDENT MOISTURE CONDITIONS, CURVE  
NUMBERS AND LAG TIMES USED/DETERMINED IN HEC-1 OPTIMIZATIONS

Watershed (USGS Gage No.)	Storm Dates	5-Day AMC/Rainfall (In)	Storm	Curve Numbers Condition II	Lag Times (Hrs)
<u>Austin, Texas</u> <u>Region:</u>					
Waller Creek at 23rd Street (08157500)	20-21 March 1957	I/0.50	97.4	95	0.16
	26-28 April 1958	I/0.69	83.0	93	0.23
	8 April 1959	I/0.03	80.2	91	0.17
	23 Sept 1959	I/0.11	77.4	90	0.19
				Avg = 92	Avg = 0.19
	3-4 June 1962	III/2.87	84.9	70	0.32
	27 Sept 1964 *	I/0.19	75.5	89	0.57
	16 May 1965 *	II/1.44	80.5	81	0.55
	18 May 1965 *	III/3.14	90.3	78	0.62
				Avg = 79	Avg = 0.52
	21-22 June 1971	I/0.03	78.7	91	0.18
	1-2 May 1972 *	III/2.33	83.4	67	0.35
	21-22 Oct 1972	II/1.47	81.9	82	0.22
	12-13 Oct 1973	III/5.94	93.3	84	1.20
				Avg = 81	Avg = 0.49
Wilberger Creek (08159150)	30-31 May 1964 *	I/0.2	76.3	89	1.14
	15-16 June 1964 *	I/0.1	76.1	89	1.03
	16-17 June 1964 *	III/4.1	90.8	80	1.04
	18 May 1965 *	II/1.6	87.4	87	1.73
	15 Oct 1967 *	I/0.2	71.3	86	1.91
	17-18 Nov 1971	II/2.0	73.0	73	1.26
	21-22 Oct 1972 *	III/3.0	84.4	69	1.80
	11 Oct 1973 *	I/0.5	82.6	93	1.13
	13 Oct 1973 *	III/2.8	97.3	92	1.90
	23-24 Nov 1974 *	I/0	65.9	82	1.69
	9-10 June 1975 *	I/0.4	80.9	92	1.46
				Avg = 85	Avg = 1.46
<u>Dallas, Texas</u> <u>Region:</u>					
Turtle Creek (08056500)	21 April 1967 *	I/0.9	88.7	96	0.73
	3-4 Oct 1971 *	I/0	76.0	89	0.50
	18 Oct 1971 *	I/0.5	91.5	97	1.00
	19-20 Oct 1971 *	III/4.2	96.4	90	1.12
	11-12 May 1973 *	I/0.1	90.9	97	0.52
	17-19 April 1976 *	II/2.0	88.9	89	0.85
				Avg = 93	Avg = 0.79
Spanky Branch (08057120)	30 Oct 1973 *	I/1.1	88.2	96	0.94
	7-8 April 1975 *	II/1.5	92.1	92	1.21
	28 June 1975 *	I/0.1	95.9	92	1.46
				Avg = 96	Avg = 1.34

\* - Storms used to obtain optimized lag times as shown in Table 1. Excluded storms had poor optimization results.

watersheds previously described in the Austin and Dallas, Texas regions were first developed utilizing USGS streamflow data and procedures of the U.S. Water Resources Council, Bulletin 17A (1976). These annual series frequency curves were developed utilizing the Pearson Type III distribution with log transformation of the peak discharge data and an expected probability adjustment applied to each curve. A generalized coefficient was weighted with the computed skew for each watershed data set as specified in Bulletin 17A. Figure 1 presents these frequency curves for the urban and undeveloped watersheds in the respective regions. The nonstationary (urbanizing) status of the urban watersheds was not considered in the construction of the annual series frequency curves.

Synthetic peak discharge frequency curves were generated utilizing the calculated and optimized CN and lag times values determined for each watershed as discussed previously, along with design storms of various frequencies. Synthetic peak discharges for the 2-, 10-, 25-, and 100-year frequencies were used to develop the curves as shown in Figs. 2, 3, 4, and 5. Specifically, NWS TP-40 rainfall amounts for the 2-, 10-, 25-, and 100-year frequencies were distributed according to an SCS Type II, 6-hour storm and input into the HEC-1 computer model to generate the peak discharges for each of the sets of calculated and optimized CN and lag time values.

#### SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Although it is impractical to make final conclusions concerning calculated versus optimized CNs and TLs based solely on the results of this study as shown in Table 1, the following points deserve mentioning.

- 1) In four of the six watershed conditions studied, the CN(O) was greater than CN(C) especially in the Dallas, Texas watersheds. The exceptions were the Waller Creek watershed for the 1962-65 and 1971-73 study periods.
- 2) The undeveloped watersheds in the two regions had greater proportions of soils with a high runoff potential in comparison with their matching urban watersheds (see Table 2). This partially explains the small difference of CN(C) values for the undeveloped and urban areas.
- 3) There was considerable variability in CN(O) and TL(O) values especially the latter. This presented some problems in selecting representative values for each parameter.
- 4) TL(C) values, utilizing Equation 3-2 and Figs. 3-4 and 3-5 of SCS (1975), appear to be high in comparison with other methods of calculating lag times. Additional study is needed to evaluate the accuracy of this particular SCS method of computing lag time.
- 5) The alternate method lag times, TL(A)s, were closer to the TL(O)s than the TL(C)s for each watershed condition. The TL(C) values were the highest of the three methods in each instance.

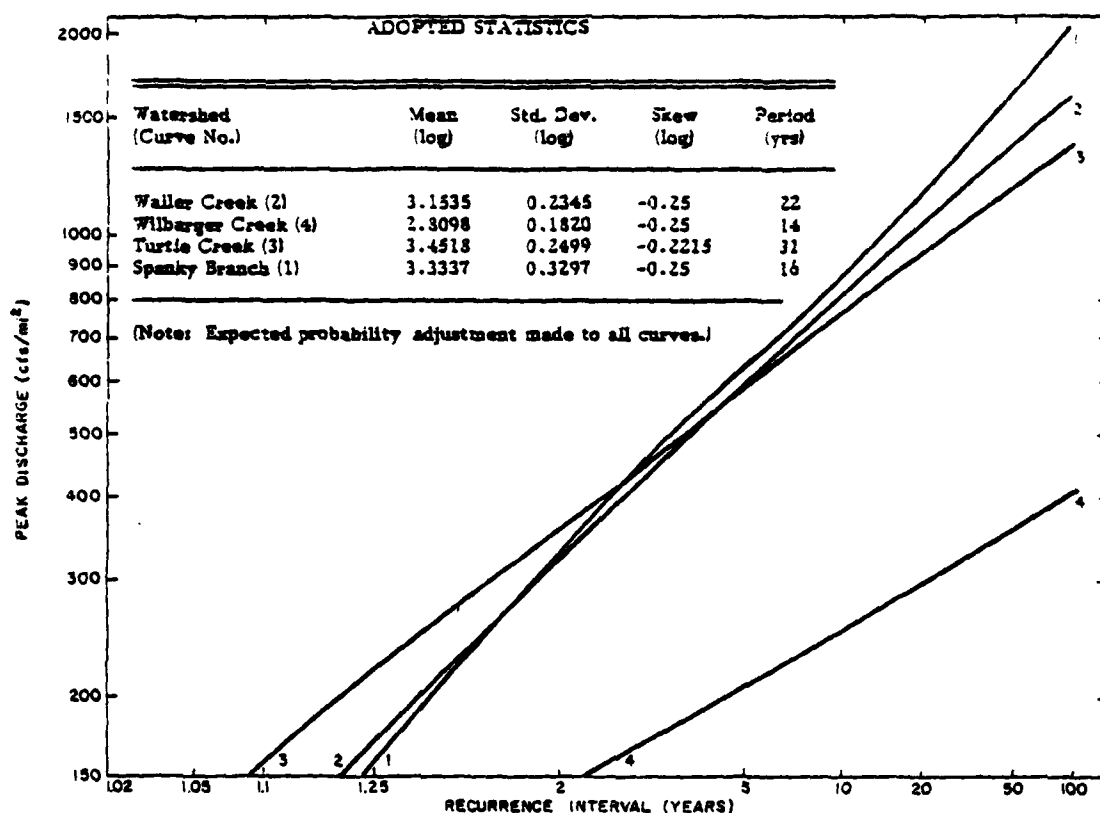


Fig. 1 Annual Series Frequency Curves

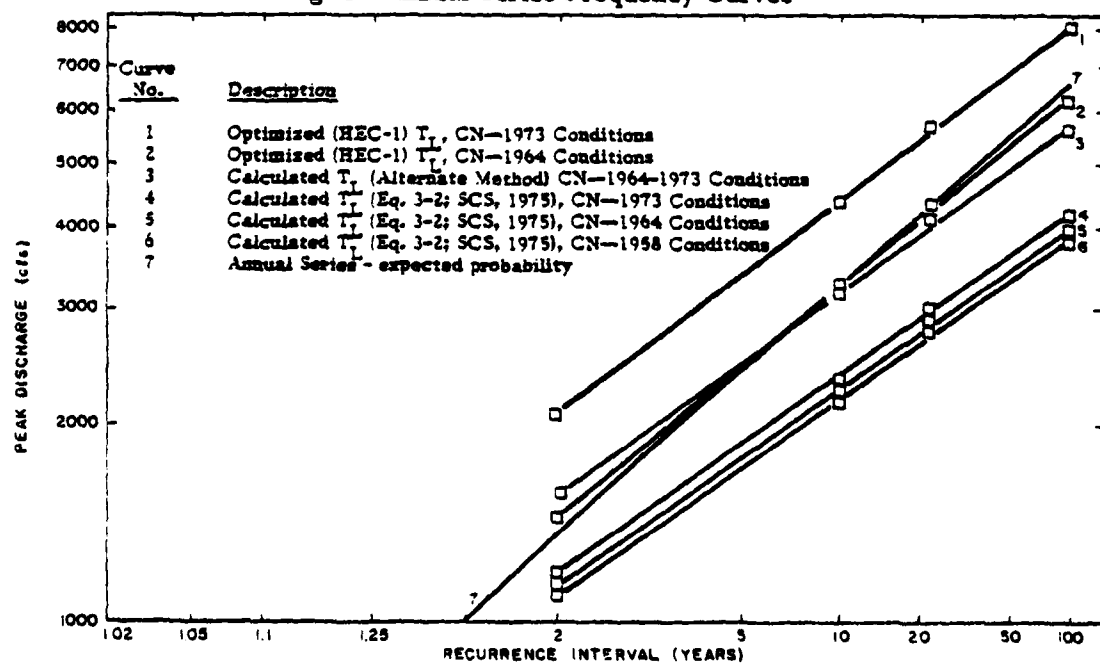


Fig. 2 Waller Creek Frequency Curves

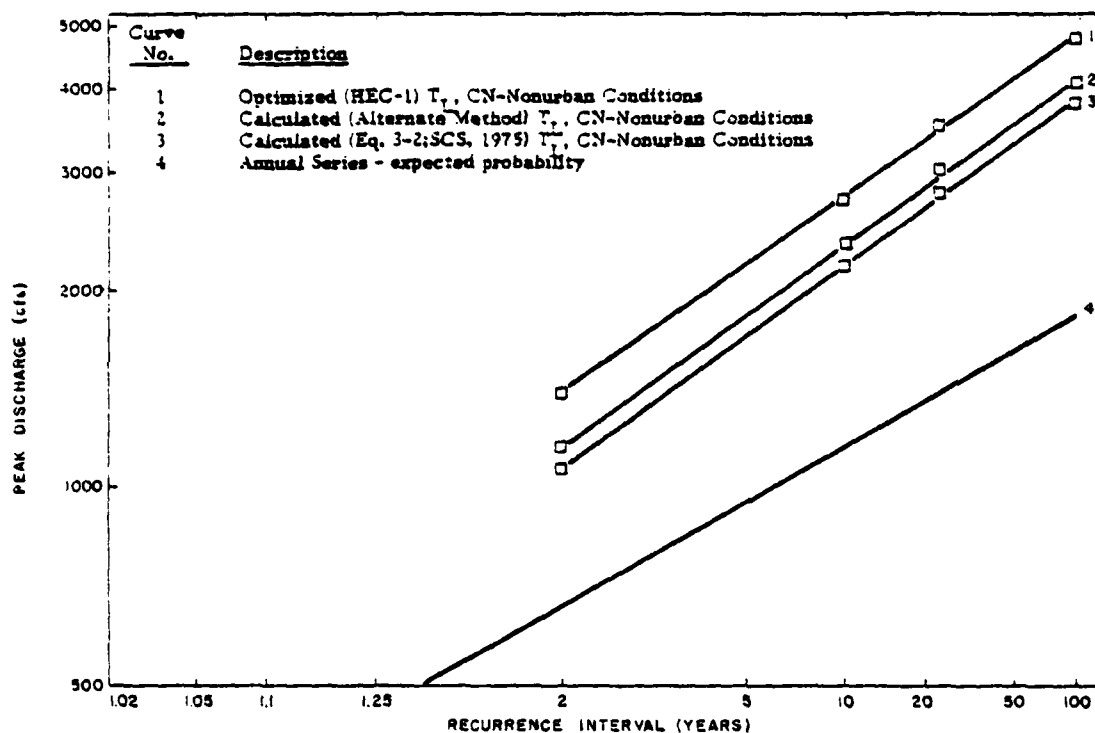


Fig. 3 Wilbarger Creek Frequency Curves

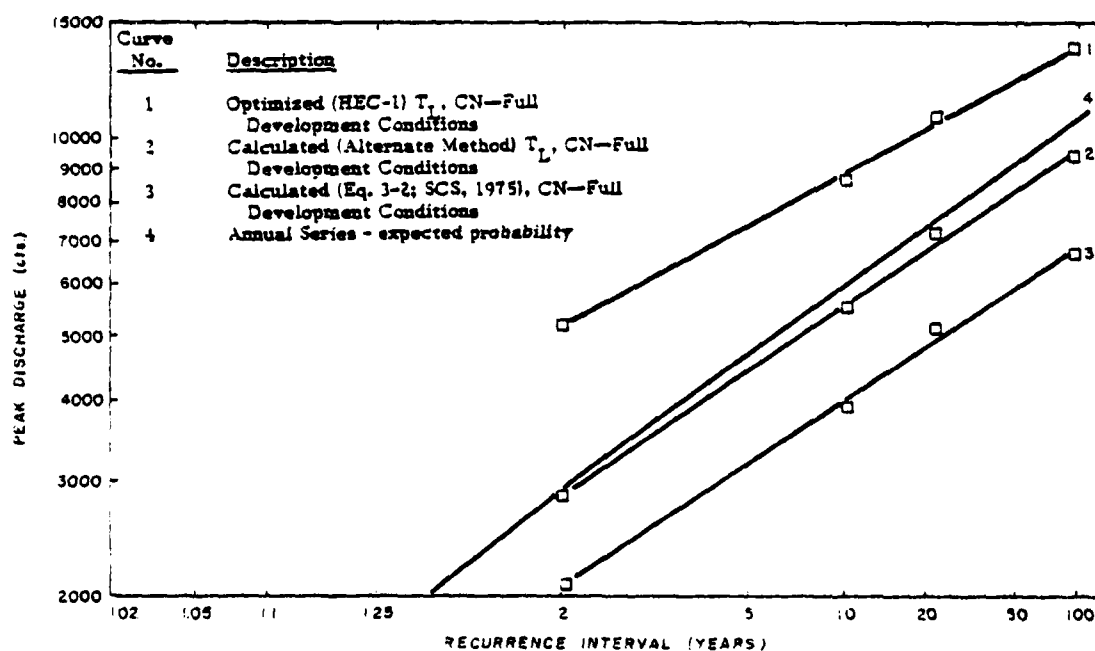


Fig. 4 Turtle Creek Frequency Curves

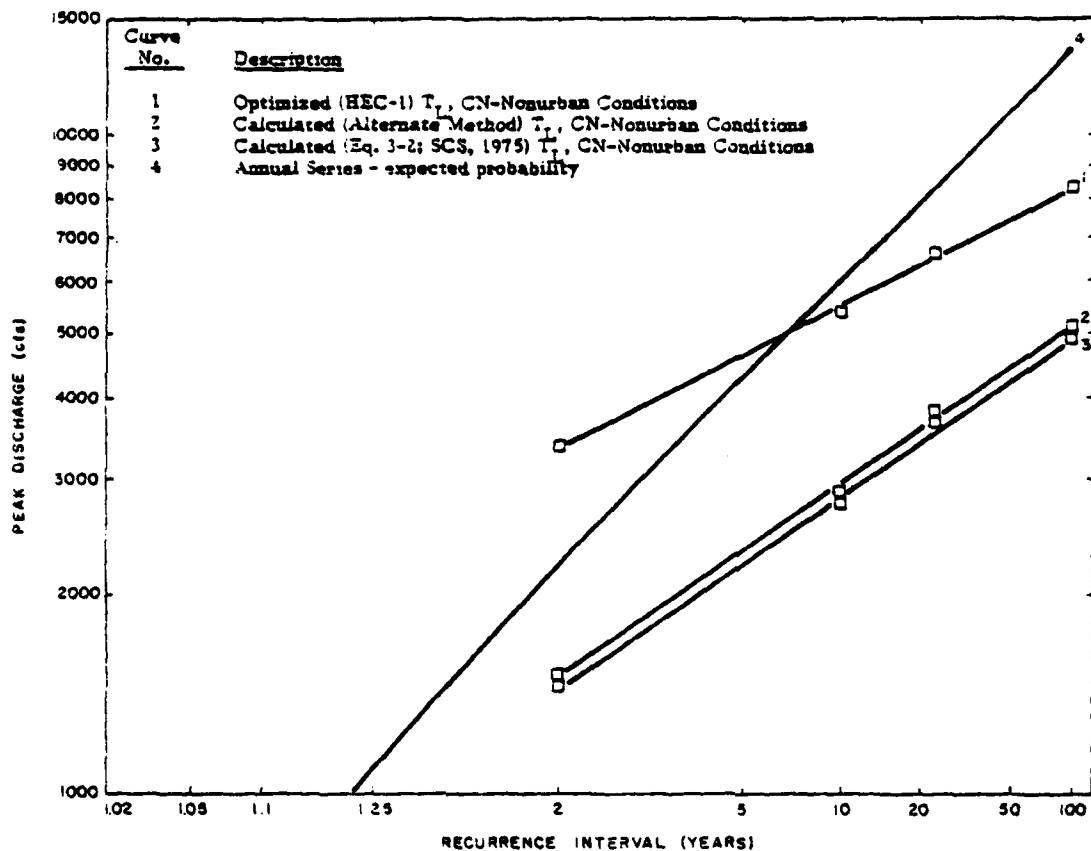


Fig. 5 Spanky Branch Frequency Curves

- 6) From Nos. 1, 4, and 5 (above) it appears that the SCS methods may provide relatively low peak discharge estimates in urban areas if using Equation 3-2 and Figs. 3-4 and 3-5 of SCS (1975).

The following general statements are made to aid in interpreting the results shown in Figs. 2 through 5 as related to the ability of the SCS procedures in predicting changes in flow frequency due to urbanization.

- 1) The annual series curves (Fig. 1) show opposite trends for the Austin and Dallas Regions when comparing peak discharges per square mile versus recurrence interval between the urban and undeveloped watersheds.
- 2) The frequency curves generated from CN(O) and TL(O) values are higher than those originating from CN(C) and TL(C) values.
- 3) The frequency curves generated from TL(A) estimates and CN(C) values closely approximate the annual series curve for the Waller Creek and Turtle Creek watersheds.

- 4) Frequency curves developed utilizing lag times calculated from Equation 3-2 and Figs. 3-4 and 3-5 in SCS (1975) are relatively low in all but the Wilbarger Creek watershed.
- 5) There is little difference shown between the Waller Creek and Wilbarger Creek synthetic frequency curves generated from CN(C) and TL(C) values. This is partially explained by the larger drainage area of Wilbarger Creek and its soils which have an overall higher runoff potential than those for the Waller Creek basin. This is not the case for the synthetic frequency curves generated from CN(O) and TL(O) or CN(C) and TL(A) values for the two watersheds.
- 6) The synthetic frequency curves representing the Turtle Creek and Spanky Branch watersheds indicate higher discharges for all frequencies for the urban versus undeveloped watersheds when comparing curves generated from the same method. The urban discharges are generally less than 50 percent and never more than 100 percent greater than those for non-urban areas utilizing this comparison.

In conclusion, the results of this analysis indicate that the generalized SCS techniques have potential in predicting effects of urbanization on flood discharges. However, additional research is needed to better define the capabilities and limitations of these techniques, especially concerning the estimation of lag time. Recommendations concerning future research should begin with a continuation of the analysis presented within this report. The scope and result of this study served to point out the need for additional work which is required to produce conclusive results. Comparisons of calculated versus optimized (from recorded storm data) watershed curve numbers and lag times can be accomplished utilizing relatively short periods of simultaneously recorded rainfall and runoff data. Various matching regional urban and nonurban watersheds having a multitude of physiographic and/or urban conditions should be incorporated into such a study.

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